MODERN EXPLOSIVES.

EXPLOSIVES are of very different degrees, both as regards pressure and effect. By pressure is meant the effort of the expansive gases measured by the strain upon the confining envelope; and by effects, not only the amount, but the kind of work.

Gunpowder may be exploded in the open air; or in the bore of a cannon; or it may be so strongly confined as to be exploded in its own volume. In the first case, the resistance to the escape of gases is due to the atmosphere; in the second, to the ball and to the atmosphere; in the third, no escape of gases being practicable before complete combustion, the pressure becomes the greatest possible for this kind of explosion. If, in the three examples given, the weights of powder being the same, all of the material be perfectly burned, the quantities of heat developed will be equal, as well the stored up work of the products of combustion. But the kinds of work done will be very different. In the first instance there is motion and disturbance in the air, spread over a large space; in the second, the explosion being partially confined under pressure and directed against the ball, would project it with a high velocity to considerable distances; and in the last case, the pressure developed would first perform work upon the elasticity of the confining envelope and, if the cohesive strength failed, would burst it. The latest experiments upon gunpowder exploded within the limits of its own volume furnish the following data: Pressure upon a square inch, 6400 atmospheres, or forty-two tons; and temperature of combustion, 3992° Fahrenheit. This substance is composed of two combustible ingredients, charcoal and sulphur, and a third, niter (potassium nitrate), which furnishes oxygen to support the combustion. It requires a considerable disturbing force to disengage the oxygen of the nitrate for combination with the carbon

and sulphur; hence powder does not belong to the class of quick explosives. Sulphur inflames at a much lower temperature and gives more heat than charcoal, and is valuable in aiding the combustion of the powder and for increasing the elastic pressure of the gases.

When a charge in the bore of a gun is first ignited, the flame spreads rapidly over the surface of the grains, developing in the first few instants of time a large amount of gas before the projectile has sensibly moved from its seat, and thus causing great strain upon the metal of the gun. When it became necessary to increase the calibers, and particularly to construct heavy rifled guns, the size of the grains was largely increased, and by this means the total surface exposed to flame in the first instants of combustion was largely decreased, and also the production of gases. However, so long as the combustion proceeds from the outside to the center of the grains, large developments of gases take place while the ball is still near the bottom of the bore, becoming continually less as it moves toward the muzzle. General Rodman, of the United States Ordnance Department, was the first to suggest a remedy for this by pressing the powder in cakes perforated with holes, so that the surface of combustion should increase as the projectile was moving in the bore. The strain upon the gun was thus decreased, and it also became possible to increase the charge and the velocity of the shot. These cakes were finally made hexagonal, and fitted each other in the chamber with a minimum loss of space.

Powder in this form, called "prismatic powder," has been adopted for heavy rifled guns in Russia and Germany. To obtain increased space for charges, the bottom of the bore has of late years been enlarged, or chambered. Large-grained powder is now made of regular shapes, to fit close, so that like charges shall occupy the same length of bore for the same powder and caliber of gun; and it is evident that attention to this, as well as to the quality of the ingredients and to the process of manufacture, was necessary to produce uniform rates of combustion and of development of gases under the same circumstances, and thus secure standards of comparison. Without such precautions, it would have been impossible to have obtained anything like uniformity of pressures or to have estimated with any certainty the strength of metal required in the gun; so that great care and research devoted to improvements in the manufacture of

gunpowder have been essential elements of success in the production of the large calibers now used in ordnance.

The introduction of heavy rifled guns has not only materially changed the construction of ships of war, but has also modified sea-coast forts and batteries, which now must be placed at greater distances from the commercial or naval depots to be protected, must possess greater resisting power, and must afford the emplacements necessary to the service of the largest artillery. Inland fortifications must likewise be placed at increased distances from the cities and depots, in order to counteract the operations of sieges, now essentially modified by the use of long-range rifled guns. With the addition of torpedoes to sea-coast defenses, neither the use of armor nor the heaviest artillery will suffice to give the advantage to ships of war in combat, provided the forts and batteries, for the protection of torpedoes as well as for their own defense, be well armed with heavy armor-piercing guns.

Gunpowder, for the important functions of war, has not been supplanted by the quick and violent explosives of later invention. On the contrary, it has been found necessary even to decrease the quickness of gunpowder in order to obtain satisfactory results from large cannons. This material is used for all calibers of artillery, large or small, for small arms of precision, and for the bursting charges of shells. It still holds an important place in military mining during the operations of sieges, although some of the quicker explosives will find here a portion of the field fitted to their special properties.

A great need is felt for some explosive powerful enough to burst with effect the heavy armor-piercing projectiles, so as to rend the sides of an iron-clad ship. The cavity in these is too small for a charge of gunpowder capable of producing the requisite effect. Neither nitro-glycerine, gun-cotton, nor dynamite No. 1 could be used as a charge in the cavity of the projectile, from the risk of exploding before the shot leaves the gun, thus rendering it unserviceable. The new substance, gelatine dynamite, or explosive gelatine, from its remarkable indifference to shocks and general insensibility to causes of explosion, joined to its extraordinary explosive strength, may furnish valuable results in this direction.

An illustration of different degrees of explosion has already been furnished in the three examples of confinement of gun-

powder, but varieties of action far more striking are developed in the comparison of gunpowder with the more violent explosives. Gunpowder ignited under confinement so strong as to resist bursting until the maximum pressure is attained, burns, owing to the confinement of the heated gases and the pressure generated, with much more rapidity than when the substance is fired in the open air; nevertheless, in comparison with some other explosives, this action is slow.

Materials whose chemical decomposition takes place with extreme rapidity have the effect of crushing rocks and breaking hollow projectiles into an inconceivable number of small fragments, the elasticity of the resisting mass not having time to come into play. Action is exerted in a special manner upon the surrounding gases, the molecules of which are urged forward with a rapidity out of all proportion with a possible change of place of the surrounding medium; and in consequence the molecules of gas tend to accumulate, driven upon one another, and to produce the effects of a strong, unyielding confinement. It is a common remark of those who use the high explosives, that the surrounding atmosphere acts like a resisting wall. These considerations furnish the interpretation of the extraordinary local effects of the explosions of this class of substances. A small quantity heaped upon an iron plate will perforate it as if pierced by a bullet; arranged along a line across the width of the plate, it will cut it in pieces; wrapped around an iron column or a tree, it will shear it. Palisades, stockades, and barriers yield to its action, and walls and houses are prostrated by it. But the very strength of these explosives forbids their use in cannons; and in a shell filled with the highest form of explosives, it is found that the minute fragments into which it is broken would render it comparatively harmless against troops. Professor Abel tested the effects of a very small charge of guncotton suspended in the cavity of a shell filled with water; this medium, conveying the normal pressure of explosion to each square inch of the cavity, really multiplied the effect of the quantity of explosive used. The shell was broken into a much larger number of fragments than by the filling of the entire cavity with gunpowder.

Cartridges of quick explosives may be detonated at certain distances from each other by the explosion of one of them. In water, this transmitted explosion is practicable at much greater

intervals than in air. The experiments instituted in 1876, in preparations for the demolition of the reef at Hallett's Point, showed that submerged cartridges of dynamite of the weight of one pound, inclosed in a wrapper of paper, were exploded by sympathy from the action of a similar amount of the substance at distances of eighteen feet, and when confined in stouter envelopes, at much less distances.

These modern explosives are applicable in submarine operations on account of the rapidity of their decomposition, with which the water, though in contact, cannot interfere. This is not the case with gunpowder, of which it is stated that the precaution of multiplying the number of points of ignition will not produce an explosion of the whole quantity under water. This, together with the superior explosive strength of the former, has caused the preference to be given to them for use in torpedoes. as well as in submarine blasting.

The term "burning" is especially given to progressive combustion, and the expression "detonation" is reserved for rapid and almost instantaneous combustion. The action of gunpowder is an instance of the former, and the decomposition of the high explosives, produced by mercuric fulminate, of the latter.

After the discovery of nitro-glycerine and gun-cotton, great difficulties were at first experienced in developing their full effect. Heat naturally was first applied; but as these substances would burn freely in the open air without explosion, confinement within a resisting envelope became necessary to produce the proper result. A cartridge of gunpowder, used as a primer, was successful in exploding the nitro-glycerine, but not the gun-cotton. M. Nobel finally employed mercuric fulminate for this purpose, and by its use, when confined in certain quantities within a metallic cap, all of the explosives of this class are detonated, except explosive gelatine, for which a particular primer is necessary.

M. Berthelot explains the detonation of these substances by a primer of fulminate as due to the heat evolved by the primer, and to the shock of its detonation, also converted into heat, acting upon a small portion of the explosive compound, which is sufficient, under existing pressure, to decompose suddenly into gas the portion in contact; and the next portion receiving the violent shock of these gases, the decomposition, by repetitions of this process, is almost instantaneously transmitted throughout

the mass. He relies entirely upon the conversion of a blow or shock into heat, and *vice versâ*, according to the theory of thermodynamics, for the explanation of the phenomena of explosion from the shock of fulminating compounds and other sources. Professor Abel holds that the explosion of one substance by another is more easily effected when the vibrations of the latter are synchronous with those of the former in a high state of tension; or, in other words, that ethereal waves of heat may be assisted by sonorous waves in producing the result. According to M. Pellet, the explosion of detonating bodies should be attributed to a particular vibratory motion which varies with their constitution and properties, and which can act independently of heat and the shock of gases produced by the explosion of the primer.

Compressed gun-cotton, dry and wet, and dynamite, laid in trains with the disks or cartridges in contact, gave for the transmission of the explosion, when detonated at one end of the train, the following rates: for dry cotton, 17,500 feet per second; for wet, 20,000 feet; and for dynamite, 21,600 feet, showing an immense superiority over the rate of combustion of gunpowder. It has been stated that the decomposition of explosives varies in quickness from the combustion of gunpowder to the detonation of the most rapid compounds; and it may be added that, for the latter substances, their decomposition may be effected between the limits of a perfect detonation and of an imperfect explosion possessing but little power. The reaction started by the first shock from the primer in a given explosive material is propagated with a rapidity depending upon the intensity of that shock, which thus determines the character of the whole explosion.

Fulminate caps, as long as they are of sufficient size to originate a reaction of great rapidity, are properly called *detonators*. Mercuric fulminate, used particularly for this purpose, gives a shock more violent and sudden than any other substance—a result due to the greatness of the pressure it develops when detonated in its own volume, nearly 40,000 atmospheres. Nitro-glycerine, dynamite, and air-dry compressed gun-cotton are detonated with mercuric fulminate. Wet gun-cotton requires a primer of the dry kind, itself detonated by the fulminate. Explosive gelatine is detonated by a special primer of nitro-hydro-cellulose mixed with nitro-glycerine. Nitro-glycerine

in the frozen state requires a larger primer of the fulminate. Granulated dynamite in the frozen state is detonated with the fulminate, but frozen in compacted cartridges it requires a primer of a soft cartridge detonated by the fulminate. Dynamite is not readily exploded with a primer of gunpowder. Nitro-glycerine is readily detonated by percussion. Dynamite and gun-cotton are not very sensitive in this respect. Professor Abel states, as the result of experiments conducted by himself, that all explosives, including gunpowder, are susceptible of violent explosion through the agency of various detonating primers; that a sufficient detonating charge will produce the full explosive effect of gunpowder in the open air without close confinement, and the same effect when submerged, without the use of the strong cases required for complete ignition in the ordinary way.

Nitro-glycerine is formed by the action of a mixture of sulphuric and nitric acids upon glycerine. The compound formed is a substitution product, several atoms of hydrogen in the glycerine having been replaced by equivalents of nitric peroxide. This compound owes its explosive sensitiveness to the comparatively feeble union of the oxygen and nitrogen in the peroxide, and a slight disturbing cause brings into play the stronger affinity of the hydrogen and carbon for the large store of oxygen contained in the new compound. It congeals between 40° and 45° in the pure state. It is of the greatest importance that in its manufacture the nitro-glycerine should be freed of acids; otherwise, it will decompose if kept, and during this process may be dangerous to handle.

Dynamite No. 1 is formed by the intimate mixture of an infusorial earth, kieselguhr, with nitro-glycerine, the proportion by weight being twenty-five per cent. of this earth to seventy-five per cent. of nitro-glycerine. It congeals at about 45°. Many other inert earths and substances have been used to form dynamites, but their absorptive capacities do not equal that of the kieselguhr. Various other mixtures have been made with nitro-glycerine which are well known in commerce, and which, therefore, need not be described—in most, a mixture of potassium or sodium nitrate and wood fiber, charcoal, or other form of carbon, and sometimes sulphur, with the addition, usually, of an absorbent.

Gun-cotton is prepared from cotton fiber treated with a mixture of sulphuric and nitric acids. The action of the nitric acid

upon the fiber makes a substitution product, gun-cotton, by the displacement of several atoms of hydrogen with equivalents of nitric peroxide. The fibrous gun-cotton is afterward very finely divided by machinery, and reduced to a pulpy state in water. It is then compressed, under pressures of four to six tons upon the square inch, into disks or other forms, and may be kept indefinitely in a wet state, saturated with water, without danger of explosion from accidental causes. It does not contain oxygen sufficient for perfect combustion, and in consequence gives out a poisonous and inflammable gas, carbonic oxide, which renders its use objectionable in large quantities, under ground, as in military mines. To remedy this defect, Professor Abel recommends the material to be impregnated with a solution of potassium nitrate. This product has the strength, but not quite the quickness of explosion, that belongs to pure gun-cotton.

Tomite, as manufactured at San Francisco, is a mixture of gun-cotton and nitrate of baryta, and forms a useful blasting powder.

Explosive gelatine is formed from nitro-glycerine and soluble gun-cotton, about ninety per cent., by weight, of the former and ten of the latter, with the addition of a small percentage of camphor to render it insensible to shocks, concussion, and other causes of accidental explosion. Of all combinations known and applied to practical use, it is said to be the most powerful. It may be preserved intact for an indefinite time under water, in this respect differing from dynamite, which rapidly loses its nitro-glycerine when so exposed. It never gives off nitro-glycerine under extreme pressure. It is unaffected by violent shocks and vibrations, and even by explosions close to it. If, in addition to these properties, it prove to be a substance stable in character, there is no reason why it should not, for military and even for industrial purposes, where great explosive strength is required, supersede all of the quick and powerful explosives in common use.

From what has been said here regarding the properties and modes of action of the several explosive substances, it appears that there is no agent which can take the place of gunpowder for the principal requirements of warfare. In blasting rock, the quicker explosives have generally the advantage in point of economy of money and time, and this is especially the case in tunneling and in submarine blasting. However, in rock weak in

cohesion, without seams where the gases might escape in large amount, and also in breaking down cliffs, as, for instance, to furnish stone for the construction of breakwaters, gunpowder still holds its old place. It is also necessary in coal mines, in order to get out large masses of the material; and in quarrying massive blocks of stone for building purposes, it is generally preferable. Nitro-glycerine is proscribed on account of its sensitiveness to exploding causes and its liquid character. Dynamite and guncotton are most useful in blasting, and particularly the former, on account of its plastic nature permitting it to be pressed into close contact with the sides of the hole. Both of these explosives are used in torpedoes and in military submerged mines, the dynamite, however, for reasons already given, being used in a granulated form.

The rapid and strong explosives are very useful in hasty operations for the destruction of abattis, palisades, stockades, barriers, and other military obstructions, and they form a regular part of the *matériel* in foreign armies. They serve likewise to remove walls, houses, and other cover for an enemy; to destroy with celerity bridges, particularly iron trussed railway viaducts; and in various ways, not necessary to mention, are useful in attack and defense. In industrial uses, they have perforated mountain ranges to open rapid communications between nations, have removed rocks and other hard obstructions from the channels of rivers, and destroyed submarine wrecks. They have been applied to break up the subsoil to depths of six to ten feet, to aid the growth of trees. They have removed masses of cast or wrought iron which accumulate below the tap-holes of cupolas or form in the crucibles of blast-furnaces. They have broken up ice dams interfering with navigation and producing inundations. They have sometimes been used in felling trees; but this is not expedient, except for hasty military operations to deprive an enemy of cover, or to create an obstruction to his advance. They are effective in removing stumps from fields and from the channels of rivers. The gigantic operations of blasting which have opened lines of communication by land and by water would probably never have been undertaken but for the discovery of the quick explosives. For unlawful uses, to serve the purposes of assassination and destruction of property, they can be applied only upon a limited scale and with nearly fruitless results, as experience has already fully demonstrated.

Attempts in this way, made on a large scale to force social changes and overturn governments, would require both time and money and an elaborate plan of operations, which could not pass without detection and suppression, unless favored by organized masses of people sufficient in numbers and power to initiate revolution and war.

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